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In several experiments, observers were given glimpses of 4-word arrays. Accuracy of word location was tested after each array. Some words, called familiar, appeared many times across the series of arrays; others, called novel, appeared only once. The ratio of novel to familiar words in an array ranged from 0:4 to 4:0. When familiar and novel words were not intermixed (in 0:4 to 4:0 arrays), localization accuracy was higher for familiar words. However, when they were intermixed, especially in 1:3 arrays, accuracy tended to be higher for the novel words. This novel popout effect was the outcome of the suppressed localizability of the familiar words (relative to the 0:4 baseline) and the enhanced localizability of the novel words (relative to the 4:0 baseline). We attribute novel popout to the automatic orientation of attention away from more fluently unfolding regions of the perceptual field (familiar objects) and toward less fluently unfolding regions (novel objects).

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Attention Capture by Novel Stimuli

by

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Laboratory studies of attention have typically used controlled-, or directed-, attention tasks in which observers are instructed either to look for prespecified targets (target detection) or to look at prespecified locations (focused attention). Since many naturalistic tasks involve directed attention, this line of research clearly has merit. However, the present research addressed a relatively neglected aspect of attention, that of attention capture. Often, attention is diffuse, or nondirected, initially but is captured suddenly by certain stimuli, as when the attention of a window shopper is caught by an item in a store-window display. At other times, attention is directed initially toward a target source of stimulation but is then captured by a potentially more important source, as when a hiker's attention is diverted from the trail ahead to a rustle in nearby bushes or a mother's attention is diverted from a conversation to the crying of her baby. Inasmuch as directed attention and attention capture may have fundamentally different processing underpinnings, the paucity of research on attention capture may have left a significant gap in our understanding of attention and related processes. We sought to explore attention capture by investigating what stimuli happen to "popout" from a brief, nondirected glance at a scene. In particular, we investigated the possible automatic capture of attention by novel stimuli.

The general question that we posed was this: When observers have only a glimpse of an array comprised of a single novel stimulus and several familiar stimuli, and are motivated to apprehend as much of the array as they can, which is most likely to be seen, the novel stimulus or any given one of the familiar stimuli? The immediate and automatic seizure of attention by novel stimuli, which we shall call novel popout, would appear to have a great deal of survival value because it would allow organisms to quickly perceive and prepare to deal with novel intrusions into their familiar surroundings. More generally, novel popout might serve as an important counterweight to the pervasive tendency for cognition to be biased or primed by well-established expectancies and schemata. Thus, novel popout could produce a degree of vigilance to environmental change and mitigate the excessive knowledge entrenchment that might otherwise result from the self-fulfilling power of schemata or established neural networks.

Indeed, a substantial literature attests to the attention-drawing power of novel stimuli. The voluminous research a few decades ago on the orienting reflex and exploratory behavior clearly established that novel objects elicit arousal and investigatory activity (e.g., Berlyne, 1960; Sokolov, 1963). Research on visual exploration by human infants indicates preferential attention to novel stimulation. For example, when confronted with two visual patterns, one novel and one familiar, infants tend to fixate more on the novel pattern (Fantz, 1964). More recently, studies of overt and nondirected scanning of naturalistic scenes by human adults indicate that novel objects, such as an octopus in a barnyard scene, are looked at longer than familiar objects, and perhaps earlier and more frequently (e.g., Friedman, 1979; Loftus & Mackworth, 1978). However, the scenes in these studies were visible for at least several seconds, so it is not clear that the results reflect the immediate and automatic orientation of attention to the novel objects. Observers might have encountered the novel objects somewhat late in their initial perusal of the scenes and only then directed their full attention to these objects.

In fact, still more recent research indicates that the detection of novel objects is actually suppressed when only a glance at a scene is allowed. Biederman, Mezzanotte, & Rabinowitz (1982, Experiment 1) examined the effect of object novelty, or incongruence, on the detection of targets in scenes exposed for only 150 ms. A drawing of a naturalistic scene, such as a living-room or street scene, was preceded by the name of a target object, such as COUCH, and was followed by a probe at a particular location. The observers' task was to say whether or not the target object had appeared at the probed location. Speed and accuracy of detection increased to the extent that the object was congruent with the rest of the scene. For example, a couch was more detectable when it was appropriately located in a living-room scene than when it hovered above the buildings in a street scene. Moreover, the detectability of a congruent object was not suppressed by the presence of a novel object elsewhere in the scene. These findings appear to demonstrate the <u>sink-in</u>, rather than popout, of novel perturbations of familiar environments.

Although the Biederman et al. study differed from prior research in its use of brief exposures, it differed also in its use of a directed-attention (viz., target-detection) task rather than a nondirected one. The present research examined the way that attention is distributed spontaneously between novel and familiar words in briefly-exposed arrays when observers are encouraged to apprehend as many words as they can.

Three experiments are reported below. Experiment 1 demonstrated novel popout in nondirected attention to briefly-exposed arrays and traced its temporal development. Experiments 2 and 3 investigated several possible bases of novel popout including figure-ground contrast, perceptual satiation of familiar words, and withdrawal of attention from familiar words.

Experiment 1

Subjects viewed a long series of 4-word arrays. To prevent eye movements, each array was backward masked after 200 ms of viewing time. Most of the words, called novel, appeared only once across the series, but others, called familiar, appeared many times. The primary manipulation was the ratio of novel to familiar words in an array: 4:0 arrays contained novel words only, and 1:3 arrays contained one novel word in the company of three familiar words. These two array compositions allowed for the computation of two forms of novel popout: between-arrays and within-array. Between-arrays novel popout occurs when localization accuracy for novel words is higher in 1:3 arrays than in 4:0 arrays. Within-array popout occurs when localization accuracy in 1:3 arrays is higher for novel words than for familiar words. In order to trace the development of novel popout, the series of arrays was subdivided into quartiles.

Method

Subjects and design. Observers were 36 students from an introductory psychology course at the University of Utah who participated in the experiment in return for extra credit toward a higher grade. Observers were exposed to the two array compositions (1:3 and 4:0) equally often in each quartile of the experimental session, yielding a 2 X 4 factorial design with repeated measures on both factors. Word type (novel vs. familiar) was a nested factor in 1:3 arrays.

Apparatus and procedures. The experiment was controlled by an 8510A Terak microcomputer system. Alphanumeric stimuli appeared in a four-cell array that was centered on a TV screen. From a viewing distance of 60 cm, the array subtended visual angles of about 1.90° vertically and 5.00° horizontally. Alphanumeric characters subtended angles of up to 0.38° vertically and 0.24° horizontally. Each stimulus presented on a trial was centered in one of the array locations. A trial comprised a succession of five types of array: warning, attention, mask, probe, and feedback. These arrays are illustrated in Figure 1.

Each location in a warning array contained a string of three asterisks. A warning array was exposed for 200 ms and was followed 1000 ms later by an attention array. Each location in the attention array contained a different word. The attention array was presented for 183 ms and followed, 17 ms later, by a mask array, yielding a virtual exposure duration of 200 ms. The mask array contained strings of 9 Xs in lieu of words and was exposed for 100 ms. After a blank interval of 500 ms a probe array was presented, in which one of the words from the attention array reappeared in all four locations.

The observers' task was to indicate in which location of the attention array this word had appeared. A response was made by pressing the appropriate one of four keys on the numeric keypad of the keyboard. The spatial configuration of the keys corresponded to that of the four array locations. Observers were asked to be as careful and accurate as possible in selecting and executing their responses. The speed and accuracy of responses were recorded by the computer. A response caused the probe array to disappear. After a blank interval of 500 ms, a feedback array was presented in which the probe word appeared for 2 s in the correct location. The next trial began 500 ms after the offset of the feedback array. After every 30 trials, the percent correct localizations for the preceding 30 trials was displayed for 5 s. A warning tone signalled the resumption of the experimental trials.

The assignment of novel and familiar words to array locations was random with the restriction that, insofar as possible, each type of word appear equally often in each location. Likewise, the probed locations were selected randomly with the restriction that, insofar as possible, both novel and familiar words be probed equally often from each array location and that the two types of word be probed in proportion to their relative frequencies. Thus, novel words were probed on precisely 25% of the 1:3 trials and, of course, on 100% of the 4:0 trials.

After being introduced to the task, observers received 28 practice trials with 4:0 arrays followed immediately by 384 experimental trials. In each 96-trial quartile of the sequence of experimental trials, each of the 8 combinations of array composition and probe location was represented 12 times. Across the 48 1:3 trials of each quartile, novel words and each of the 3 familiar words were probed 3 times at each array location. Outside of these constraints, the assignment of words to locations and the sequencing of array compositions and probes was random. A testing session lasted approximately 55 min.

Stimulus material. The words were drawn from the Kucera and Francis (1967) frequency norms. They were 1042 singular nouns, 3 to 8 letters in length, with rated frequencies of occurrence in the language from 6 to 492 per million. Of these, 12 were selected randomly to serve as familiar words and the rest served as novel words. The 12 familiar words were divided into 4 sets of 3 words, and each set served as the familiar words for 9 observers.

Results

Units of analysis. Accuracy and speed of responding tended to positively covary across conditions. However, response accuracy proved to be considerably more sensitive to experimental manipulations than did response speed. This is to be expected in view of the heavy emphasis on accuracy in the instructions and task feedback. Therefore, only the accuracy data are summarized below. Moreover, the data from the practice trials were not analyzed and are not summarized. The accuracy data from the experimental trials are summarized in Figures 2 and 3.

Preliminary analyses. Localization accuracy on experimental trials was lowest in the bottom array location but did not vary across the 4 sets of familiar words. None of the interactions involving these minor variables approached statistical reliability.

Between-arrays analyses. A 2 X 4 (Array Composition X Quartile) repeated-measures analysis of variance indicated that localization accuracy for novel words was higher in 1:3 arrays than in 4:0 arrays, $F(1, 35) = 11.83$, and improved across quartiles, $F(3, 105) = 10,90$. As Figure 2 suggests, the former effect, which defines between-arrays novel popout, interacted with quartile, being most pronounced in the fourth quartile of the session, $F(3, 105) = 3.14$.

Within-array analyses. A 2 X 4 (Word Type X Quartile) repeated-measures analysis of variance of the data for 1:3 arrays substantiated the improvement in localization accuracy across quartiles, $F(3, 105) = 4.05$, but did not indicate an overall superiority of novel words over familiar words, $F(1, 35) = 1.50$. However, word type did interact with quartile, $F(3, 105) = 6.61$, and post-hoc tests confirmed what is evident in Figure 3; a reliable within-array popout effect emerged in the fourth quartile of the session. The apparent popout of familiar words in the first quartile did not quite reach the Newman-Keuls criterion of statistical reliability.

Discussion

Novel popout were evident both between- and within-arrays. Since these effects were observed despite the mixed sequence of array compositions and the 200-ms duration of array exposure, they are not readily attributable to array-specific search strategies, eye movements, or some combination thereof. Rather, attention appears to move automatically, rapidly, and covertly to the novel words in 1:3 arrays. However, the novel popout effects took some time to develop and tended to be confined to the last quartile of the session. This suggests that the familiar words must be repeated many times before novel popout begins to occur.

These novel-popout effects are somewhat curious, if not anomalous, because they appear to be directly at odds not only with the novel sink-in effect observed by Biederman et al. (1982) but also with a well-established form of implicit memory that we shall call perceptual memory (e.g., Jacoby & Dallas, 1981). In particular, when individual words are exposed briefly, accuracy of identification is higher for those that had been seen before in the experiment (e.g., familiar words) than for those that had not (e.g., novel words). Thus, when 1:3 arrays of words are exposed briefly, it is curious that accuracy of identification is not higher for the familiar words than for the novel words. Experiments 2 and 3 sought to establish the boundaries and generality of novel popout and to explore its processing bases.

Experiment 2

Array composition was manipulated across four levels: 1:3, 2:2, 3:1, and 4:0. The 3:1 arrays provided an assessment of the possibility that novel popout is just another instantiation of the general phenomenon of figure-ground contrast. Familiarity may be a perceptual dimension in terms of which figure-ground contrast can be defined. Thus, a single novel word in a field of familiar words may stand out as figure against ground. If this hypothesis has merit, then figure-ground contrast should be equally pronounced when a single familiar word appears in a field of novel words, and familiar popout should be observed in 3:1 arrays. The 2:2 arrays allowed a test for novel popout when the possibility of figure-ground contrast is minimized. If novel popout is due to some inherent perceptual advantage of novel words over familiar words, then it should obtain in 2:2 arrays. In the absence of either familiar popout in 3:1 arrays or novel popout in 2:2 arrays, the continued presence of novel popout in 1:3 arrays would indicate that it is due to neither figure-ground contrast nor some inherent perceptual superiority of novel words but rather to factors unique to 1:3 arrays.

Method

Subjects and design. Observers were 52 university students recruited in the manner described with respect to Experiment 1. Formally, the design was a 4 X 4 (Array Composition X Quartile) factorial with repeated measures on both factors. Again, word type was a nested factor in the mixed array compositions.

Procedures. The apparatus, procedures, and general word pool were the same as those used in Experiment 1. As in Experiment 1, the attention arrays were backward masked after 200 ms. Following 16 trials of practice with 4:0 arrays, observers were presented a sequence of 384 experimental trials. The experimental trials were organized into four, 96-trial segments. The four array compositions appeared equally often, but in a random sequence, in each segment. For each array composition, novel and familiar words were probed in proportion to their relative frequencies of presentation. That is, novel words were probed on 25% of the 1:3 trials in each 96-trial segment, 50% of the 2:2 trials, 75% of the 3:1 trials, and, of course, 100% of the 4:0 trials. Outside of these constraints, the location probed on each trial was selected randomly. The four segments were administered in different orders to different observers such that, across observers, each segment was represented equally often in each quartile of the experimental sequence. This counterbalancing scheme eliminated the confound that would otherwise exist between quartiles and the sequence of arrays within quartiles.

Since the overall pattern of results in Experiment 1 did not vary appreciably across the four sets of familiar words, only one of these sets, selected arbitrarily, was used in Experiment 2. The array locations marked for novel words were filled by a random drawing from the word pool.

Results

Analyses were performed only on the data from the experimental trials and without regard to array location. The findings of interest are summarized in Figure 4.

Between-arrays analyses. Neither quartile, $F(3, 153) = 1.58$, nor its interaction with array composition, $F < 1.00$, attained statistical significance in an analysis of variance of localization accuracy for novel words. However, accuracy was found to vary reliably across the four array compositions, $F(3, 153) = 5.18$. Using the 4:0 condition as a baseline, post-hoc tests revealed that between-arrays novel popout was statistically reliable only in 1:3 arrays.

Within-array analyses. A 2 X 3 X 4 (Word Type X Array Composition X Quartile) analysis of variance was performed on localization accuracy for novel and familiar words in the three mixed array compositions (viz., 1:3, 2:2, and 3:1). Although this analysis did indicate a reliable improvement in localization accuracy across quartiles, $F(3, 153) = 4.11$, neither word type nor array composition approached significance as main effects, Fs < 1.00. However, the important Word Type X Array Composition interaction approached significance, $F(2, 102) = 2.51$, $p = .09$, and tests of the simple main effects of word type detected a reliable within-array popout of novel words in just the 1:3 arrays, $F(1, 51) = 4.13$. None of the remaining interactions approached significance, Fs < 1.00.

Discussion

Novel popout was again observed in 1:3 arrays, but neither novel popout nor familiar popout was observed in either 2:2 arrays or 3:1 arrays. The restriction of novel popout to 1:3 arrays suggests that it is dependent on the 1:3 array configuration and not on either stimulus novelty per se or figure-ground contrast. If novel popout were due to an intrinsic property of novel stimuli, then it should have emerged in 2:2 arrays as well. Moreover, the absence of a complementary familiar pop-out effect in 3:1 arrays constitutes evidence against interpretations of novel popout that appeal to figure-ground contrast.

In contrast to Experiment 1, the popout of novel words from 1:3 arrays did not vary reliably across quartiles. However, in terms of average magnitude, the within-array effect was about 40% larger in the second half of the experimental sequence than in the first half, and the between-arrays effect was about 58% larger. Indeed, separate analyses of the two halves of the sequence revealed that both effects attained reliable levels only in the second half: $t(51) = .63$ and 2.39 for the within-array effect in the two halves, and $t(51) = 1.88$ and 2.70 for the between-arrays effect in the two halves.

Although novel popout is not attributable exclusively to intrinsic differences between novel and familiar words, it must, by definition, derive to some extent from these differences. The final experiment explored what it is about word novelty, or familiarity, that produces novel popout.

Experiment 3

We consider here two possible perceptual consequences of word familiarization, perceptual satiation and perceptual fluency, either of which could contribute to the popout of novel words from 1:3 arrays and account for the tendency of this phenomenon to be most pronounced on later trials.

According to the perceptual-satiation hypothesis, the units comprising the perceptual representation of a word satiate after many repetitions of the word in a particular context. Although the evidence for satiation of lexical and semantic processing is questionable (e.g., Cohene, Smith, & Klein, 1978), satiation of physical (e.g., featural) processing remains a viable possibility. A build-up of perceptual satiation across trials would reduce the fluency with which familiar words are perceived. As a consequence, given only a brief glimpse of a 1:3 array, the single novel word would tend to be perceived more fluently than any of the familiar words, yielding a within-array popout effect. Although perceptual satiation alone would produce within-array popout, an additional process is needed to produce between-arrays popout. One possibility is that, in 1:3 arrays, attention migrates rapidly, covertly, and automatically to the location in the perceptual field that is unfolding most fluently. This would cause attention to concentrate on the single novel word in a 1:3 array but be distributed across all four novel words in a 4:0 array, yielding a between-arrays popout effect.

According to the perceptual-fluency hypothesis, the repetition of a word in a particular context enhances, rather than reduces, its perceptibility. Perceptual fluency has been observed to increase across one or two repetitions of words in a particular context but then level off (e.g., Feustel, Shiffrin, & Salasoo, 1983; Whitlow & Cebollero, 1989). However, since novel popout tends to emerge only after many repetitions of the familiar words, the hypothesis considered here requires an effect that extends far beyond the first few repetitions. By itself, such a process would cause the familiar words in a 1:3 array to be perceived more clearly and quickly than the single novel word, yielding a novel sink-in, rather than popout, effect. However, both within-array and between-arrays novel popout would be explained if it is assumed (a) that attention moves rapidly, covertly, and automatically to the regions of the perceptual field that are unfolding the <u>least</u> fluently and (b) that this concentration of attention more than offsets the otherwise low perceptual fluency of the novel words in 1:3 arrays. An hypothesis similiar to this was developed by Myles-Worsley (1986).

The findings of the first two experiments fail to discriminate decisively between these opposing hypotheses. Experiment 3 attempted to make this discrimination by intermixing 4:0 and 1:3 arrays with 0:4 (i.e., all-familiar) arrays. A comparison of 4:0 and 0:4 arrays affords one relatively straight-forward test. If repeated exposures to words produce perceptual satiation, then localization accuracy should be higher in 4:0 arrays than in 0:4 arrays. By contrast, if repeated exposures enhance perceptual fluency, then localization accuracy should be higher in 0:4 arrays than in 4:0 arrays.

The inclusion of 0:4 arrays in the experimental sequence affords additional information not provided by the foregoing experiments. Specifically, a comparison of 0:4 and 1:3 arrays provides a between-arrays measure of attention allocation to the familiar words in 1:3 arrays. If attention is withdrawn from the familiar words in these arrays and allocated to the novel words, as both of the above accounts of novel popout claim, then localization accuracy for familiar words should be lower in 1:3 arrays than in 0:4 arrays. Such a result would not only help to elucidate the bases of novel popout, but it would indicate that the within-array novel-popout effect has been underestimated in our prior studies because localization accuracy for familiar words in 1:3 arrays was not adjusted to take into account the high 0:4 baseline level of localization accuracy.

Finally, the equal mixture of 4:0, 1:3, and 0:4 arrays in the experimental sequence provides a check of an additional factor that might have contributed to novel popout in the prior studies. In all of the prior studies, novel words were both presented and probed for more often than familiar words. In Experiment 1, for example, the mixture of 4:0 and 1:3 arrays gave novel words a 5 to 3 edge over familiar words. This may have yielded a bias to search, even covertly and automatically, for novel words throughout the experimental sequence. In the present experiment, this possible bias is reversed; familiar words have a 7 to 5 edge over novel words. If novel popout is still observed, then this covert search-bias account of the phenomenon will be discredited.

Method

Subjects and design. Observers were 42 university students who were recruited via the same procedures used in Experiments 2 and 3. Formally, the design was a 3 X 4 (Array Composition X Quartile) factorial with repeated measures on both factors. Word type (novel vs. familiar) was an additional factor nested within the 1:3 condition.

Procedures. The procedures were virtually identical to those employed in Experiment 2, the main difference being that only three array compositions, one being 0:4, were intermixed in each quartile of the session. Two different sets of 4 words were randomly drawn from the word pool to serve as familiar words. Each set was administered to half of the observers. The familiar words of each set were assigned randomly to the four locations of each of the 0:4 arrays. For each of the 1:3 arrays, a random three of the familiar words were assigned to a random three of the array locations. An additional 480 words were randomly drawn to fill the array locations reserved for novel words.

Altogether, there were 48 practice trials followed by a sequence of 288 experimental trials. In contrast to Experiment 2, the practice trials consisted of only 0:4, rather than 4:0, arrays. This extended practice with 0:4 arrays served two purposes. One was to prefamiliarize observers with the familiar words and, thereby, accelerate the build-up of perceptual satiation or perceptual fluency for these words across experimental trials. The other was to see if performance on 0:4 arrays changes appreciably when other array compositions are introduced into the sequence of trials.

Results

The analyses were confined to the variables of theoretical interest, namely, word type (novel vs. familiar), array composition, and quartile. None of the effects involving quartile approached statistical significance, perhaps owing to the extensive prefamiliarization of the repeated words provided by the protracted 0:4 practice. Hence, these effects are disregarded below. The findings of interest are summarized in Figure 5.

Analyses of novel popout. Localization accuracy for novel words was reliably higher in 1:3 arrays than in 4:0 arrays, $F(1, 41) = 8.59$. This between-arrays popout effect replicates rather precisely that found in Experiments 1 and 2, indicating that between-arrays novel popout is relatively independent of the context of array compositions within which the 1:3 and 4:0 arrays are embedded.

The within-array popout effect in this experiment also was comparable, in average magnitude, to that observed in Experiments 1 and 2. However, in the present study, the difference in localization accuracy between novel and familiar words in 1:3 arrays did not attain statistical significance, $F(1, 41) = 1.90$.

Analyses involving 0:4 arrays. The data for the 48 trials of practice on 0:4 arrays were organized into six blocks. Localization accuracy increased across 0:4 practice from 54% to 69%, $F(5, 205) = 7.89$, and then dropped to 62% in the first quartile of the experiment sequence. However, by the second quartile, localization accuracy returned to an asymptotic level of 68%. This quick recovery indicates that the perceptual fluency of familiar words in 0:4 arrays was relatively stable and relatively unaffected by the introduction of 1:3 and 4:0 arrays into the experimental sequence.

A comparison of 0:4 with 4:0 arrays confirmed what is transparent in Figure 5: Localization accuracy was much higher in 0:4 arrays, $F(1, 41) = 29.05$. This effect indicates that word familiarization produced a buildup in perceptual fluency rather than in perceptual satiation. In addition, localization accuracy for familiar words was reliably higher in 0:4 arrays than in 1:3 arrays, $F(1, 41) = 13.94$. This effect defines a between-arrays sink-in effect for familiar words in 1:3 arrays.

Discussion

The data support the perceptual-fluency interpretation of novel popout. Perceptual fluency of the repeated words appears to have built up across the 48 prefamiliarization trials, causing localization accuracy on the experimental trials to be substantially higher in 0:4 arrays than in 4:0 arrays. It is important to note that our use of a word-localization task in lieu of a word-report task discounts an interpretation of this effect in terms of a guessing or response bias in favor of familiar words.

The greater perceptual fluency of the familiar words should operate to make them easier than the novel words to localize and identify in 1:3 arrays. Thus, the perceptual fluency of familiar words in 1:3 arrays must have been offset by a competing factor, and this factor appears to have been the transfer of attention from the familiar words to the novel words. This attentional factor is suggested by two findings: Localization accuracy was suppressed below the 0:4 baseline for the familiar words in 1:3 arrays, and, as usual, it was elevated above the 4:0 baseline for the novel words in these arrays.

An appropriate assessment of within-array popout effects must, therefore, take into account the different baseline levels of localization accuracy for novel and familiar words. In Figure 6, localization accuracy for novel and familiar words from 1:3 arrays is plotted against their respective baselines. Accuracy of localization of the novel words in the 1:3 arrays was consistently above the 4:0 baseline. However, in every quartile except the first one, accuracy of localization for the familiar words was below the 0:4 baseline. An analysis of variance of the corrected accuracy scores revealed a highly reliable within-array novel-popout effect, $\underline{F}(1, 41) = 18.62$. The apparent interaction between word type and quartile only approached statistical significance, $\underline{F}(3, 123) = 1.93$, $\underline{p} = .13$.

Throughout our research, the within-array popout effect has been consistently smaller, more fragile, and more elusive than the between-arrays effect. The large within-array popout effect revealed in Figure 6 implies that the estimates of this effect in the prior studies were much too low. Finally, the popout of novel words from 1:3 arrays occurred in spite of the fact that, over the entire session, familiar words were presented and probed for more frequently than novel words. This, along with the random sequencing of the different array compositions, discredits interpretations of novel popout in terms of a covert-search bias toward novel words.

In summary, three important conclusions may be drawn from the results of Experiment 3. First, multiple repetitions of words across arrays yields a build-up in perceptual fluency rather than perceptual satiation. Second, the within-array popout of novel words in 1:3 arrays is a joint product of two between-arrays effects: a between-arrays popout of novel words and a between-arrays sink-in of familiar words. Third, the elusiveness of the within-arrays popout of novel items in the prior studies is attributable to the lack of a 0:4 baseline.

The familiar sink-in effect is impressive in its own right. This effect is not attributable to the wasting of attentional resources, resources that might otherwise have been directed to the familiar words, on a strategy of looking for novel words in 1:3 arrays. Since the different array compositions were randomly intermixed, any such effect would have retarded localization accuracy in 0:4 arrays as well. Furthermore, the fact that localization accuracy for 0:4 arrays was as high throughout most of the experimental sequence as it was at the end of the 0:4 practice sequence indicates that the introduction of novel words into the experimental sequence did not produce a protracted retardation of localization accuracy in 0:4 arrays. It appears to have been the actual presence of the novel words in the 1:3 arrays, not the anticipation of them, that produced both the popout of novel words and the sink-in of familiar words.

General Discussion

General Summary and Conclusions

Mean localization accuracy for the full range of array compositions examined in Experiments 2-4 is shown in Figure 7. The 1:3 and 4:0 arrays were included in all three studies, and the values of localization accuracy shown for these arrays in Figure 7 are weighted interexperimental averages.

We draw five main conclusions from the data summarized in Figure 7: (1) From a comparison of 0:4 and 4:0 arrays, we conclude that objects are more difficult to localize in novel scenes than in familiar scenes; (2) from a comparison of 1:3 arrays with 0:4 arrays, we conclude that the placement of a novel object in an otherwise familiar scene inhibits localizability of the familiar objects (i.e., yields familiar sink-in); (3) from a comparison of 1:3 arrays with 4:0 arrays, we conclude that the placement of a novel object in a familiar context enhances localizability of the novel object (i.e., yields novel popout); (4) from a comparison of 1:3 arrays with 2:2 and 3:1 arrays, we conclude that the addition of more novel objects to the scene does not affect familiar sink-in but reduces novel popout; and (5) from a comparison of all five array compositions, we conclude that the cost of familiar sink-in outweighs the benefit of novel popout. For 1:3 arrays, the benefit in localization accuracy for novel words (relative to the 4:0 baseline) was approximately 5%, and the cost for familiar words (relative to the 0:4 baseline) was approximately 4.6%. Weighting the benefits and costs by the 1:3 ratio of novel to familiar words yields a net cost of about 2.20% per word for this array composition. Thus, novel popout appears to occur at a substantial cost in accuracy of object localization in briefly-exposed scenes.

Tentative Conceptualization

We propose that perceptual fluency builds up for objects and events to which observers are repeatedly exposed in particular environmental contexts. The result is that, given only a glimpse of a scene, or other improvished viewing conditions, objects in novel scenes are perceived less fluently, and localized less accurately, than those in familiar scenes (Conclusion #1 above). In scenes containing a mixture of novel and familiar objects, the segmentation of the perceptual field into fluently and nonfluently unfolding regions provides a perceptual marker for the locations of the novel objects. Attention flows rapidly and automatically away from the fluently unfolding regions of the perceptual field (Conclusion #2) and toward the nonfluently unfolding regions (Conclusion #3). For a given array size, which was 4 words in the present research, a given proportion of attention is withheld from each familiar object and dispersed evenly across the novel objects. Thus, as the ratio of novel to familiar objects increases, the amount of attention withdrawn from each familiar object remains constant, but that received by each novel object decreases (Conclusion #4). What is unique about the 1:3 array configuration, then, is that it produces a relatively large amount of released attention, all of which is concentrated on a single novel object.

Although our account of novel popout is consistent with the general pattern of findings portrayed in Figure 7, it does not accommodate certain details, such as the failure for novel popout to be more pronounced in 2:2 arrays than in 3:1 arrays. On the other hand, given the restricted range of localization accuracy across array compositions, the statistical power of Experiment 3 was probably not sufficient to detect the relative small differences that would be expected between these arrays. Our tentative model fails also to accommodate the finding, summarized in Conclusion #5, that the benefit of novel popout did not fully offset the cost of familiar sink-in. There are several possible bases of this finding. One is that the amount of localization accuracy purchased by a unit of attention increases with the perceptual fluency of the objects. Thus, the transfer of a unit of attention from a fluently perceived familiar object to a nonfluently perceived novel one would yield a net cost in localizability of the objects. A second possibility is that attention reallocation itself costs a certain amount of attention, and a third possibility is that some of the attention withdrawn from familiar objects is dissipated among objects and events other than the novel objects in the scene. Clearly, further research is needed to test, refine, and extend our tentative account of novel popout.

There are doubtlessly plausible accounts of our findings other than the one we proffer above. However, as we have noted, our data discredit accounts that appeal to overt or covert search strategies, stimulus novelty per se, figure-ground contrast, and perceptual satiation. Our data run counter to additional interpretations as well, namely, those based on the strong memory associations that presumably develop among the familiar words and between each of them and the four array locations. These associations could cause perceptual and retrieval problems to build up for the familiar words. The perceptual representations of the familiar words might become so tightly interconnected that the presentation of any one of the familiar words activates to a high level the representations of all of them. Thus, when observers have only a glimpse of a 1:3 array, they may be quite sure of the locations at which the familiar words appeared but quite unsure of which familiar words appeared at which locations. Consequently, observers would know by default the location of the novel word but might sometimes have to guess the location of a familiar word. In addition, the associations between the familiar words and the four array locations might yield retrieval interference. When a particular familiar word is presented as a probe, then the retrieval interference between the different locations associated with that word may make it difficult to judge the location at which the word appeared most recently. Although these possible perceptual and retrieval problems might contribute to novel popout, they should operate to reduce performance in 0:4 (all-familiar) arrays as well. Thus, these hypothetical processes cannot readily explain the the relatively accurate localization of words in 0:4 arrays; in particular, they cannot account for our observation of familiar sink-in.

Phenomena Related to Novel Popout

There remains the task of relating our findings to other empirical phenomena, some of which appear to be at odds with novel popout. We consider below perceptual memory, novel sink-in, other forms of popout, inhibition of return, and schema-driven perception.

Perceptual Memory

We noted earlier the apparent inconsistency between novel popout and implicit, perceptual memory. Words exposed at near-threshold durations are more likely to be identified correctly if they had been perceived before in the experimental context, like our familiar words, than if they had not, like our novel words (e.g., Jacoby & Dallas, 1981). In fact, in a preliminary study (DeWitt & Johnston, 1989), we compared novel words and familiar words in terms of their latencies of identification when they came into view gradually. The mean latencies were 1818 ms for novel words and 1390 ms for familiar words, a perceptual-memory savings of 428 ms. Indeed, the superiority of 0:4 arrays over 4:0 arrays in terms of localization accuracy may be considered another manifestation of perceptual memory.

Despite the fact that familiar words are more localizable than novel words when they are presented separately, just the reverse appears to be the case when they are presented together in a 1:3-type format. Figure 6 indicates that this reversal is attributable nearly as much to a retardation in localization accuracy for the familiar words (i.e., between-arrays familiar sink-in) as to a facilitation in localization accuracy for the novel words (i.e., between-arrays novel popout). It is this marked reversal in the relative localizability of novel and familiar words that suggests strongly to us that when novel objects appear in an otherwise familiar scene, attention is withdrawn from the familiar objects and directed toward the novel objects.

Our resolution to the apparent contradiction between perceptual memory and novel popout is that an observer's awareness of an object and its location is determined conjointly and independently by both the fluency of its perceptual encoding and the amount of spatial attention directed to it. These two processes work in harmony to yield the difference in localization accuracy between 0:4 and 4:0 arrays. Attention is evenly distributed across all four words in both types of array, but the words in 0:4 arrays, being familiar, are more fluently perceived. However, the two processes work in opposition in 1:3 arrays. The familiar words in these arrays are encoded more fluently than the novel words but receive less attention.

Novel Sink-in

The novel-popout effects observed repeatedly in our studies contrast sharply with the novel sink-in effect observed by Biederman et al. (1982). This empirical disparity is attributable to several of the differences between the two sets of studies. One potentially important difference is that Biederman et al. used a directed-attention task rather than a nondirected-attention task. The two tasks may mobilize somewhat different processes and yield different phenomena. For example, the specification of a novel target just before the presentation of the scene might have facilitated the fluency with which the object was perceived and, consequently, obscured the usual low-fluency demarcation of its location in the unfolding perceptual field.

A second difference is that Biederman et al. did not include an all-novel baseline condition in their study. When a novel object appears in a scene, a portion of attention might be released from the familiar objects and focused on the novel object, making an object like a couch more perceptible in the context of a street scene than in the context of a random collection of objects. That is, although Biederman et al. did not observe a within-array popout of novel objects from otherwise intact scenes, they might have observed a between-arrays popout of novel objects had they collected all-novel baseline data. On the other hand, if attention had been withdrawn from the familiar objects in scenes containing a novel object, then a sink-in effect might have been expected for familiar objects. Yet, no such effect was observed; the familiar objects were no less detectable in scenes containing a novel object than in completely intact scenes.

However, the scenes used by Biederman et al. might have militated against familiar sink-in. They presented depictions of naturalistic scenes that are characterized by stable spatial configurations of the familiar objects. Observers of naturalistic scenes can predict with high accuracy not only that a particular object will be in a scene but where it will be located. The withdrawal of attention may not inhibit localization of objects whose locations can be determined a priori on the basis of normative probabilities. This feature of naturalistic scenes may militate against novel popout as well; it may so strongly bias perception that novel objects are, at least momentarily, mistaken for the familiar objects that could occupy those locations in nature. For example, at first glance, a couch hovering in the sky might be perceived schematically as an airplane or a blimp.

Finally, the two sets of studies differed in terms of the nature of the relationship between the observers and the scenes. In the Biederman et al. research, observers encountered depictions of naturalistic scenes but were not in vivo spectators at the scenes. Object novelty was defined in terms environmental contexts other than the one in which the observers were actually located. In our studies, the observers viewed the scenes (i.e., arrays), and acquired knowledge about the objects (i.e., words) contained in them, in vivo. Object novelty was defined in terms of the probabilities of occurrence of particular words in the context of the experiment itself. A possible consequence of this difference is that the fluency variations across the visual field were greater in our studies. Novel popout may be more pronounced when one is viewing the scene itself, as was the case in our research, than when one is viewing only a depiction of the scene, as was the case in the Biederman et al. research. A couch hovering in the sky might capture the attention of observers who are actually there, at the scene. Likewise, the novel word might not capture attention when only a drawing of a 1:3 array is viewed, along with drawings of other scenes, in a totally different context (e.g., on a city street).

We do not dismiss the Biederman et al. findings as being trivial or artifactual. Rather, we believe that they provide an interesting and provocative contrast to our own findings. A reconciliation of the two sets of findings would no doubt shed new light on both novel sink-in and novel popout.

Other Forms of Popout

Attention appears to be captured automatically by other stimulus attributes besides stimulus novelty. Jonides and Yantis (1988) observed an apparent capture of attention by abruptness of stimulus onset. In their original report, Yantis and Jonides (1984) interpreted this form of attention capture in terms of a visual coding system (viz., transient as opposed to sustained) that is highly specialized to detect both abruptness of onset and movement (see Breitmeyer & Ganz, 1976). We are not aware of any empirical demonstration of the automatic capture of attention by moving stimuli. However, since both motion and abrupt onsets are detected by the transient system, we assume that attention tends also to be drawn automatically to any moving stimulus in a field of stationary stimuli.

Since the novel words in our research differed from familiar words along physical and semantic dimensions that are coded by the sustained system, the mechanism underlying novel popout is no doubt different from that underlying the popout of abrupt and moving stimuli. However, all three forms of popout may serve some of the same adaptive functions. Automatic attention to the sudden appearance of a moving novel object in an otherwise static and familiar environment might enhance the ability of the organism to deal quickly and effectively with it. The rapid detection of intrusions defining predators or prey might promote the rapid execution of flight or attack responses.

Inhibition of Return

Posner and some of his colleagues have observed an inhibitory phenomenon that is similar to familiar sink-in (e.g., Posner & Cohen, 1984; Posner, Rafal, Choate, & Vaughan, 1985). They replicated the finding that attention is captured automatically by a stimulus that appears abruptly at a point in space eccentric to the point of fixation. In addition, however, they observed an inhibition, lasting 1-2 sec, in the subsequent redirection of attention to that same location. This inhibition of return should economize visual search for targets by promoting the scanning of new locations in each 1-2 sec period of search. In addition, this effect could produce a form of attention capture. Given a second glance at a scene that had been presented a moment earlier, inhibition of return should render observers likely to attend to new locations and, therefore, relatively novel objects. However, this form of popout is different from the one introduced in this report in at least two ways: It is more transitory, and it is based on location novelty rather than object novelty.

Both inhibition of return and novel popout should serve the adaptive function of keeping the organism vigilant to the most informative elements of the environment. However, we submit that novel popout serves the broader function of mitigating the self-perpetuating nature of knowledge-driven, or schema-driven, perception and attention.

Schema-Driven Perception

There is considerable empirical support for the widely held assumption that perception of familiar objects and scenes is guided and biased by active schemata or knowledge networks corresponding to beliefs and expectancies (e.g., Bargh, 1982; Bower, Black, & Turner, 1979; Fazio, Sanbonmatsu, Powell, & Kardes, 1986; Friedman, 1979; Hochberg, 1978; McClelland & Rumelhart, 1986; Rumelhart & McClelland, 1982). Schema-driven perception provides for, among other phenomena, the rapid perception of coherent, as opposed to jumbled, scenes (e.g., Biederman, Glass, & Stacy, 1973) and the perceptual restoration of missing or degraded components of scenes (e.g., Rumelhart, Smolensky, McClelland, & Hinton, 1986). The top-down operation of active schemata account for the well-established ability of individuals to attend selectively to relevant (i.e., schema-consistent) stimuli and screen out irrelevant, potentially distracting stimuli (James, 1890; Johnston & Dark, 1986).

Schema-driven perception appears to be at odds with novel popout. On the one hand, attention appears to be captured by expected, or familiar, stimuli. On the other hand, attention appears to be captured by unexpected, or novel, stimuli. Our proposed resolution to this paradox is that the two phenomena operate as opponent processes. In most familiar settings, there are no blatantly novel or incongruent objects and schema-driven perception dominates. However, when a totally unexpected object is present, novel popout dominates. We suggest that the capacity for novel popout to oppose schema-based processing is its most important function. By ensuring a degree of vigilance to environmental change, novel popout may foster the appropriate revision of schemata. Thus, novel popout may militate to some extent against the strong tendency for knowledge to be self-sustaining and resistant to change.

Concluding Comment

In summary, novel popout appears to be a robust and replicable phenomenon of nondirected attention. We submit tentatively that it is based on the covert, rapid, and automatic orientation of attention toward the less fluently unfolding regions of the visual field. Although, novel popout is associated with a benefit in terms of detection and localization of novel intrusions into familiar environments, it is accompanied by a cost in terms of attention to and, presumably, awareness of the familiar objects. As noted above (Conclusion #5), the cost outweighs the benefit, yeilding lower overall apprehension of scenes containing novel objects than of those containing only familiar objects. However, inasmuch as at least the presence, if not the locations, of most of the familiar objects are known in advance of the scene, the real cost in the withdrawal of a portion of spatial attention from these objects is likely to be relatively trivial and greatly outweighed by the tremendous benefit to organisms of vigilance to environmental change.

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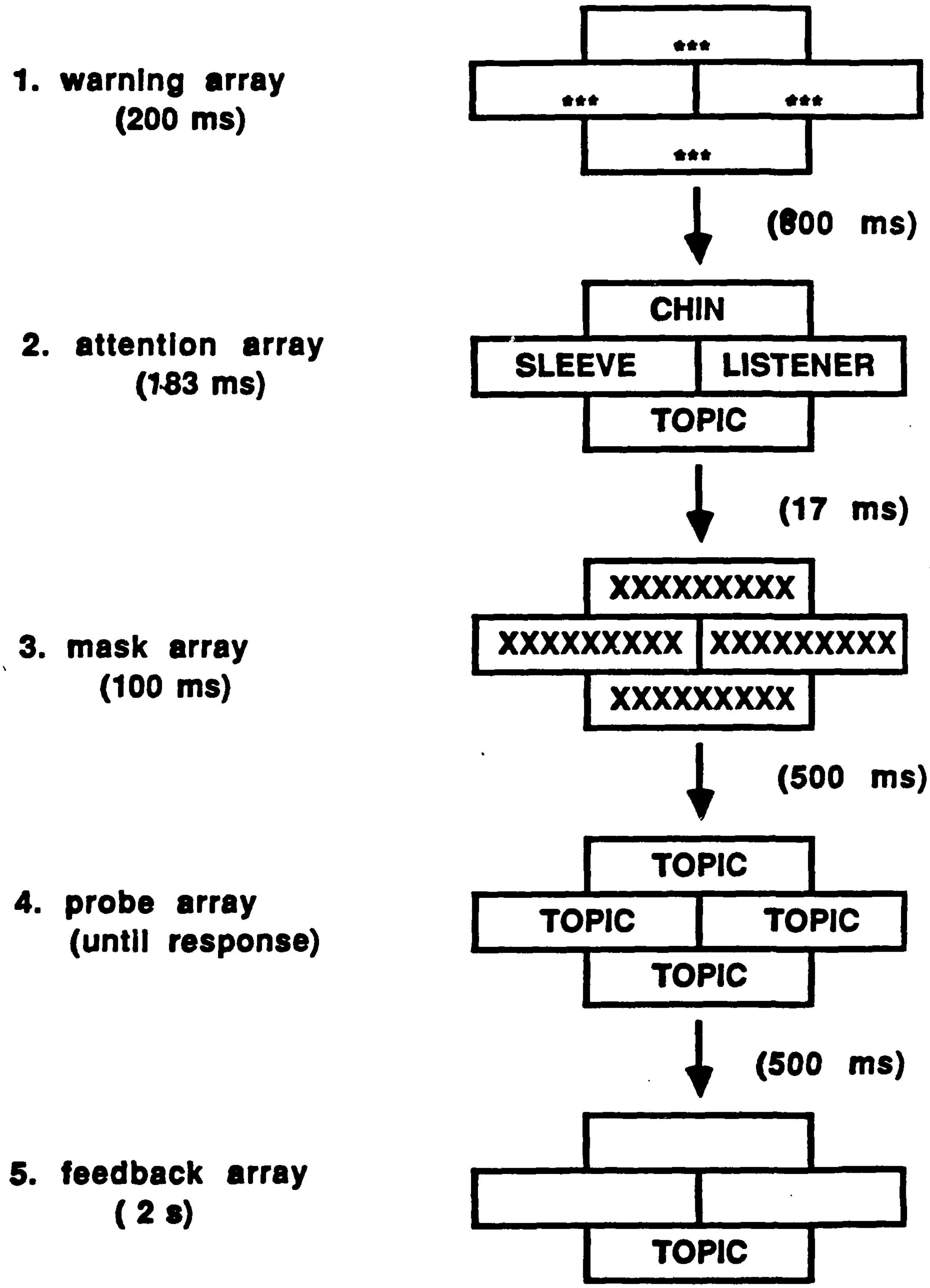

Figure 1. Sequence and timing of the five types of array comprising a trial in Experiment 1.

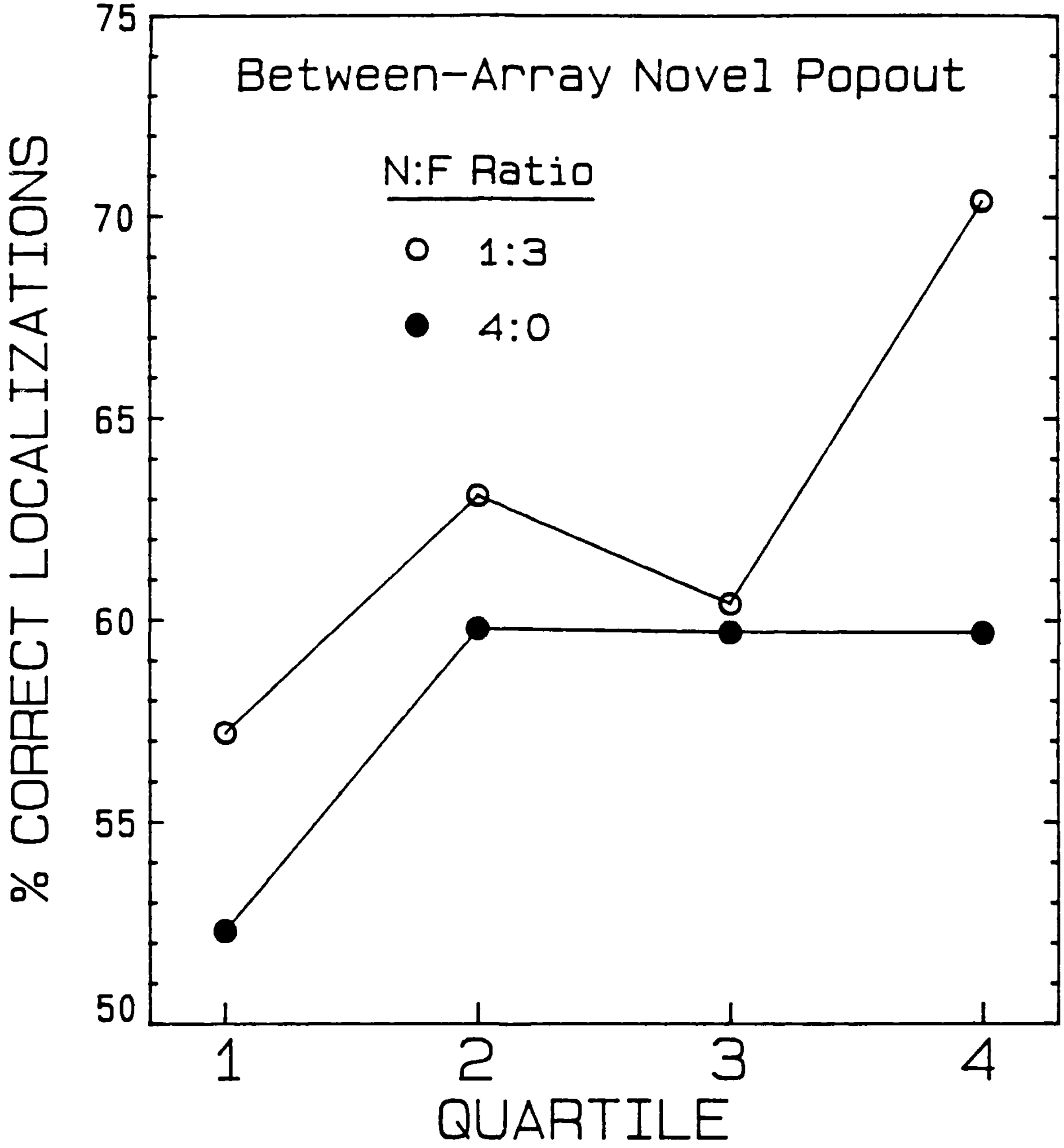

Figure 2. Localization accuracy in Experiment 1 for novel words in 1:3 and 4:0 arrays as a function of session quartile.

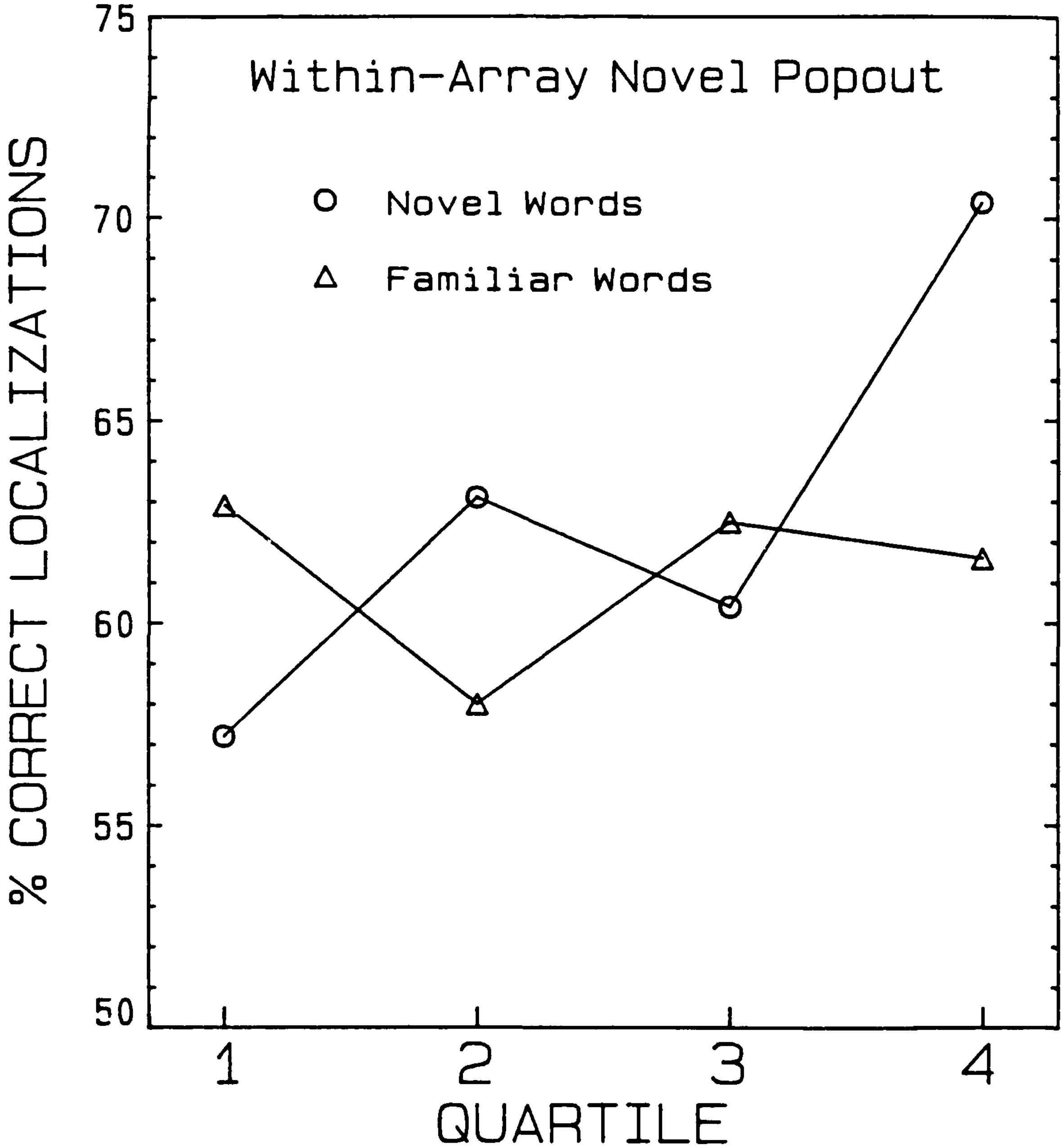

Figure 3. Localization accuracy in Experiment 1 for novel and familiar words in 1:3 arrays as a function of session quartile.

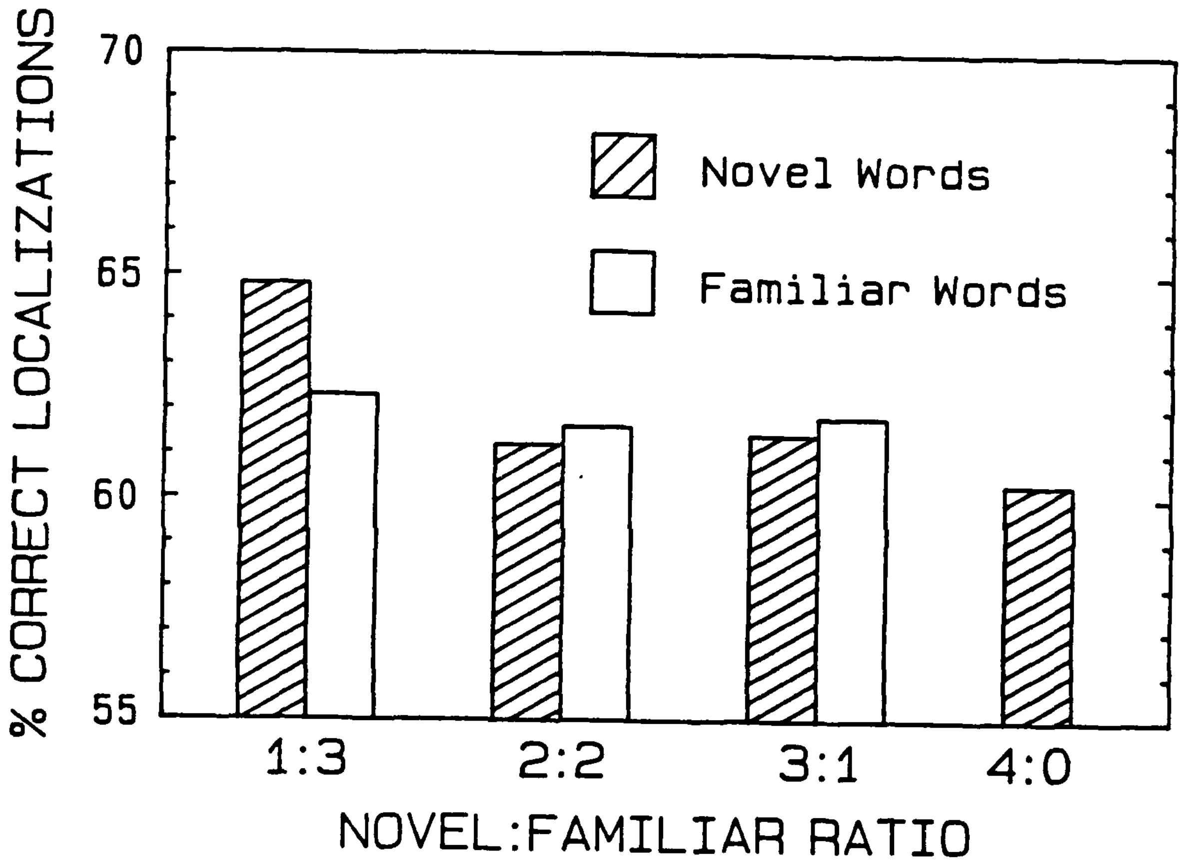

Figure 4. Localization accuracy in Experiment 2 for novel and familiar words as a function novel:familiar ratio.

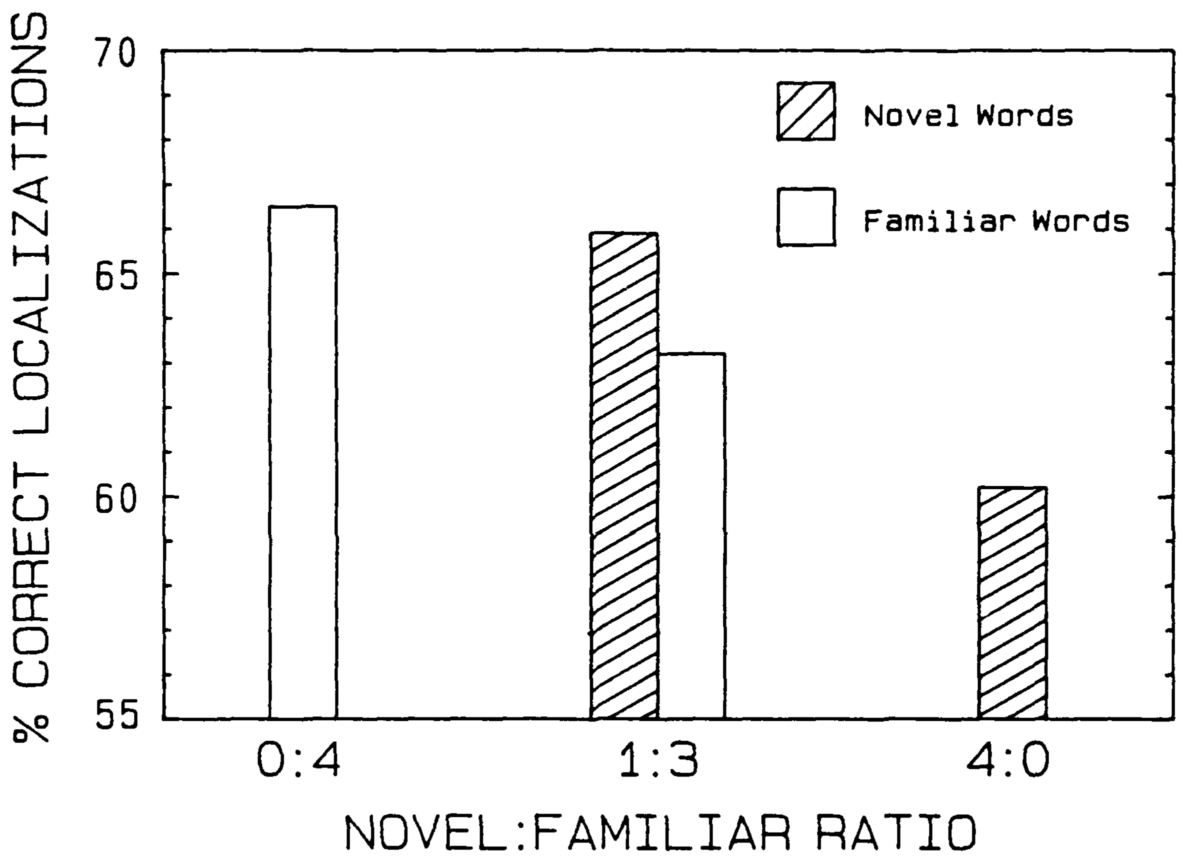

Figure 5. Localization accuracy in Experiment 3 for novel and familiar words as a function of novel:familiar ratio.

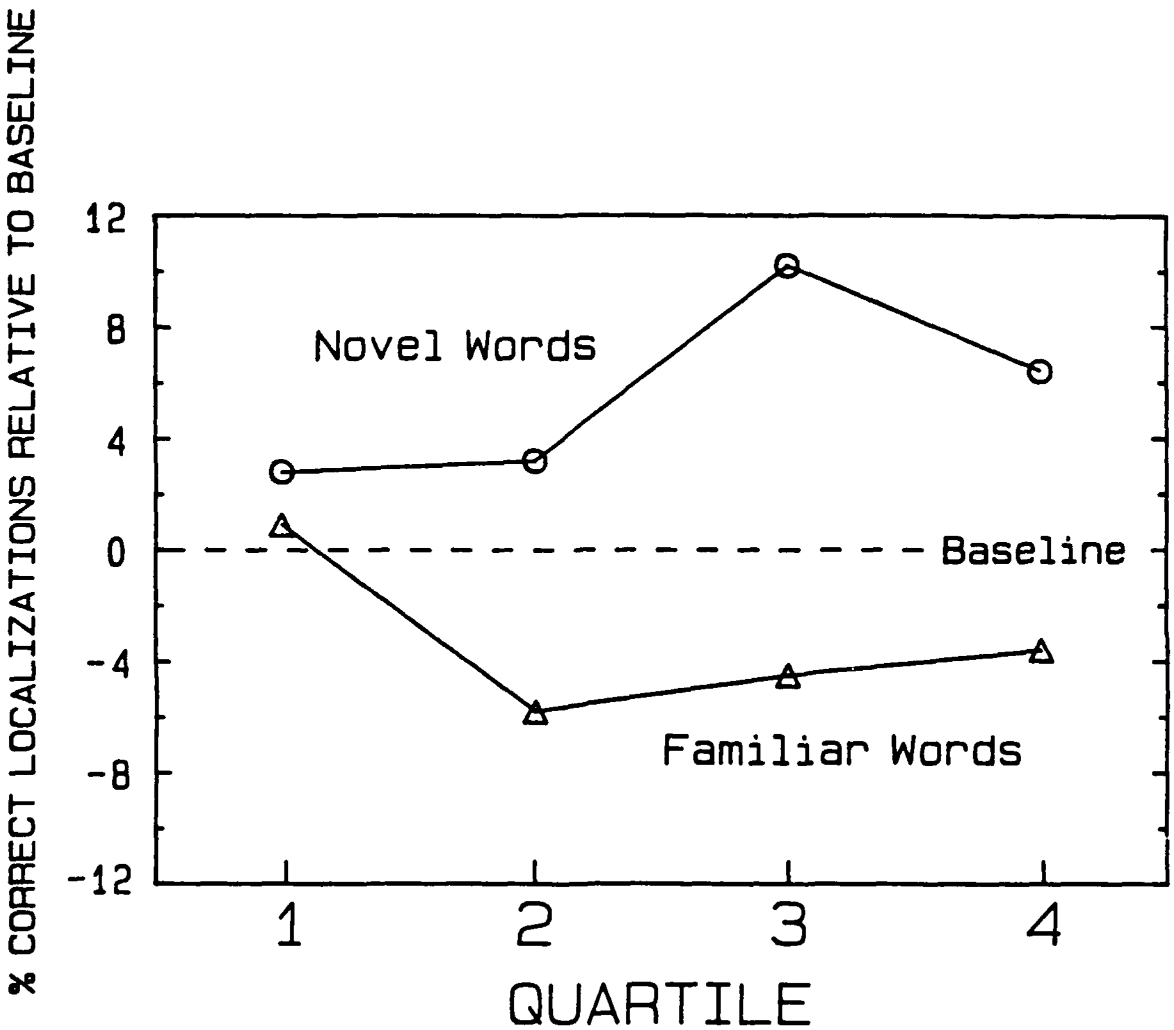

Figure 6. Departures from the 4:0 and 0:4 baseline levels of localization accuracy in Experiment 3 for novel and familiar words, respectively. (The baseline levels were approximately 60% and 66.5% for 4:0 and 0:4 arrays, respectively.)

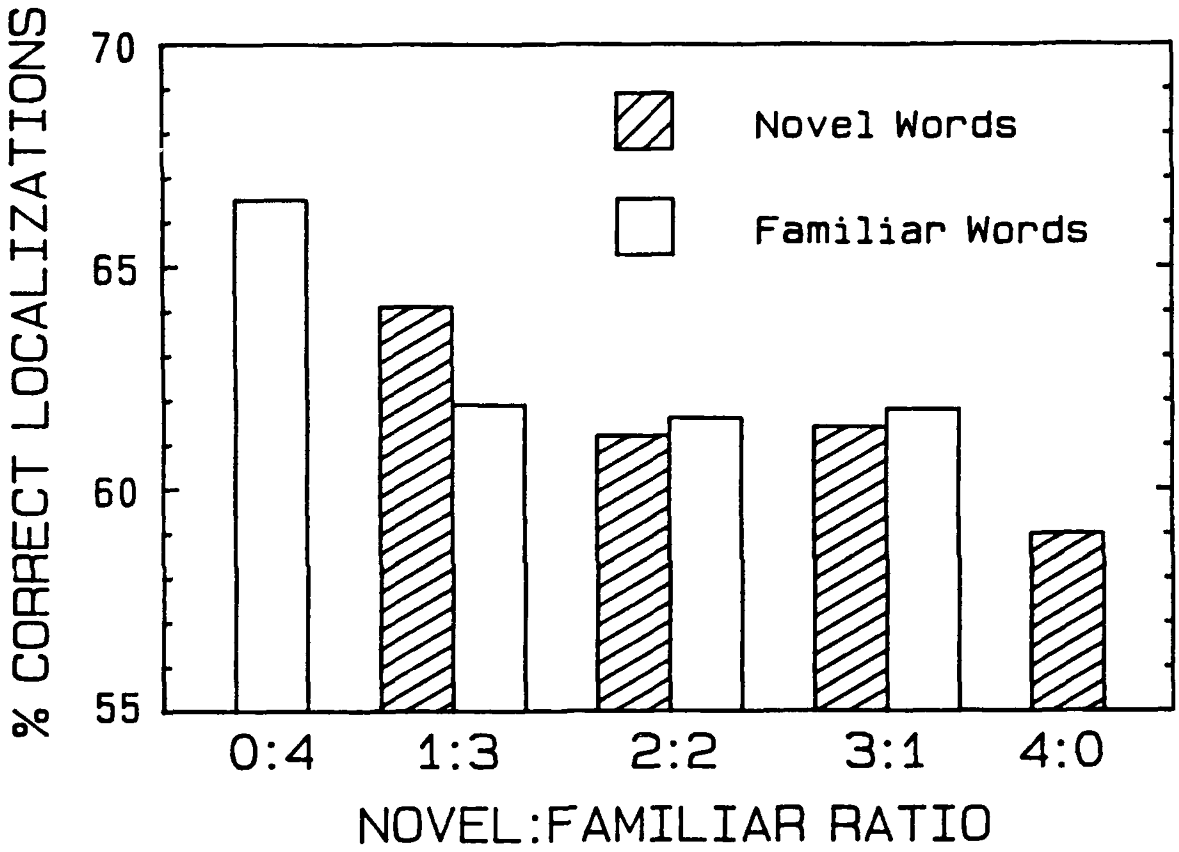

Figure 7. Localization accuracy for novel and familiar words for the full range of novel:familiar ratios examined collectively in Experiments 1-3. (Accuracy values for the 1:3 and 4:0 ratios represent weighted averages across the three experiments.)